

A golden age for maser surveys

Shari Breen | University of Sydney Research Fellow

IAU S336 Astrophysical Masers: Unlocking the Mysteries of the Universe

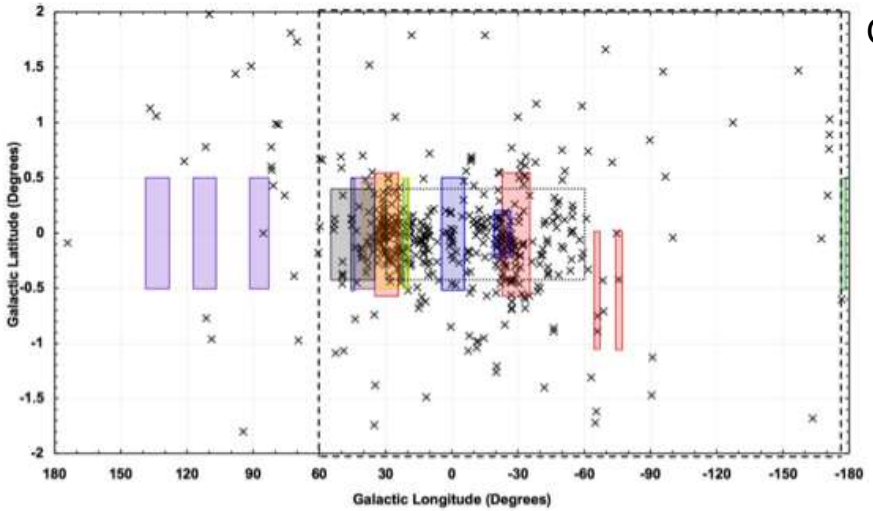
THE UNIVERSITY OF SYDNEY

Outline

- Focus on a few large surveys in the southern hemisphere that I have been involved in
  - The methanol multibeam (both 6.7 GHz methanol and excited-state OH)
    - 12 GHz methanol
    - 22 GHz water
  - HOPS
  - SPLASH
  - MALT45
- Not going to talk about other significant blind or (e.g. ongoing ones such as GLOSTAR, THOR, KuGARS) targeted surveys

The Methanol Multibeam Survey (MMB)

- Unbiased, systematic search for 6.7 GHz methanol masers within the Galactic plane and the Magellanic clouds
  - 6.7 GHz methanol masers exclusively trace sites of high-mass star formation (Minier et al. 2003, Xu et al. 2008, Breen et al. 2013)



Green et al. (2009)

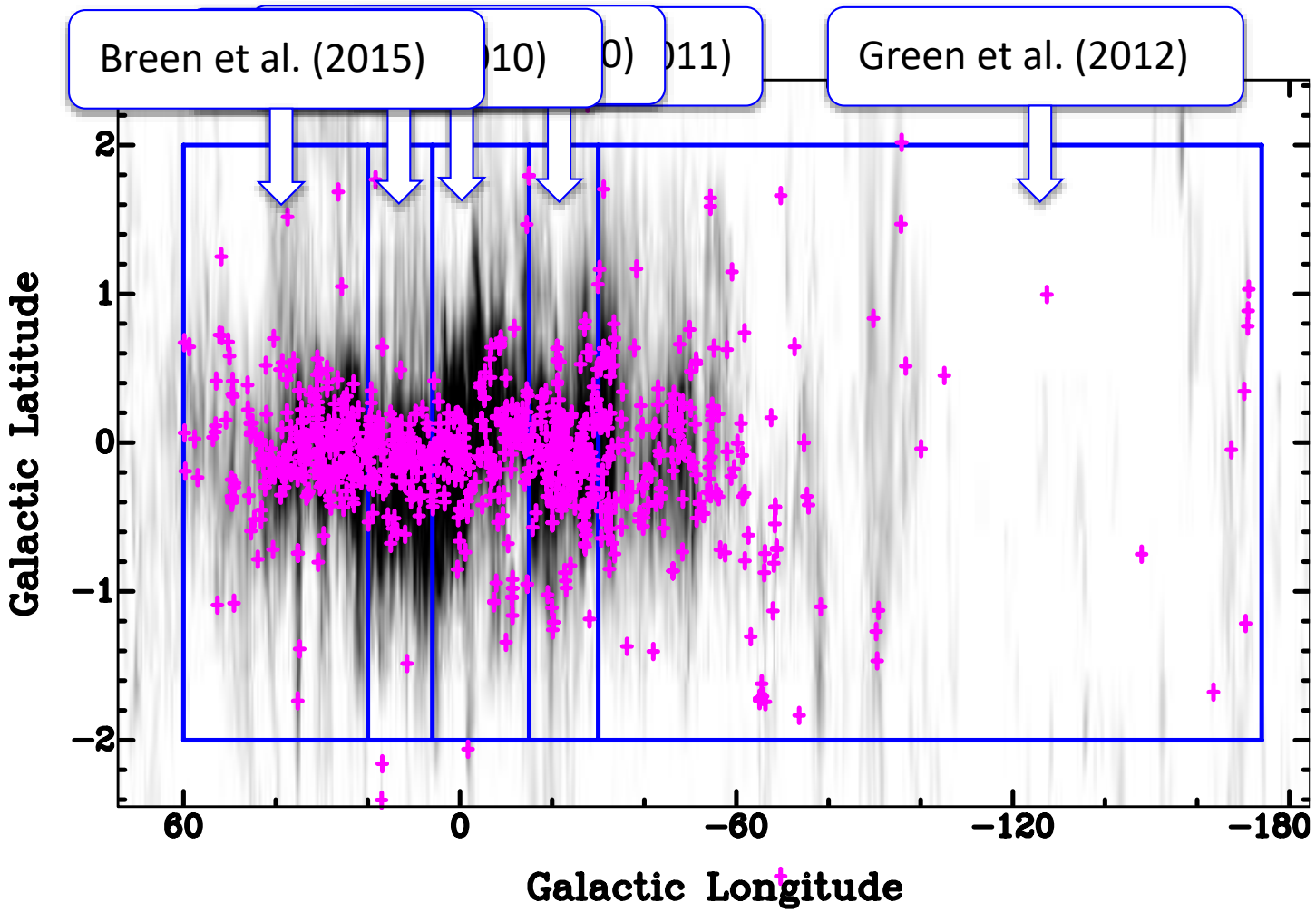






- 3σ survey sensitivity of ~0.51 Jy
- 972 detections, ~40% new sources
- All with precise positions
- Provide targets for parallax and star formation studies

The Methanol Multibeam Survey (MMB)

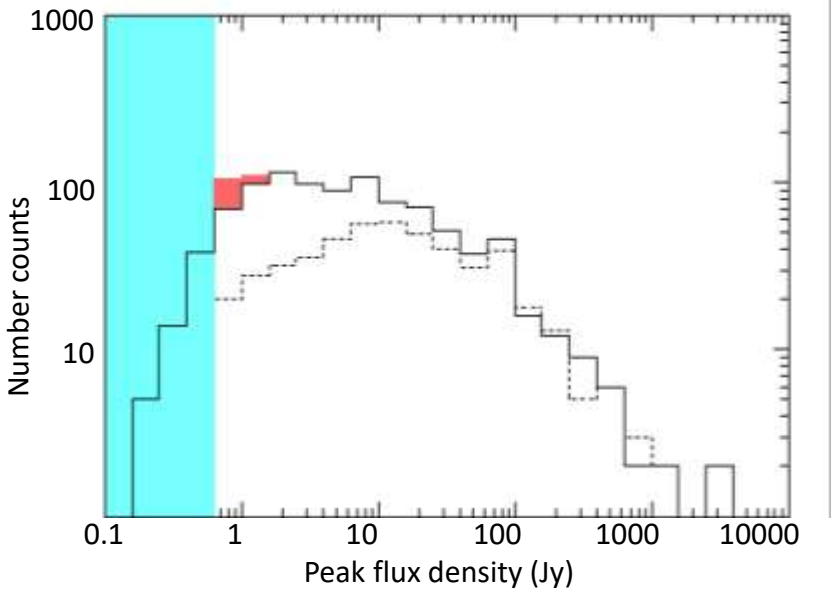


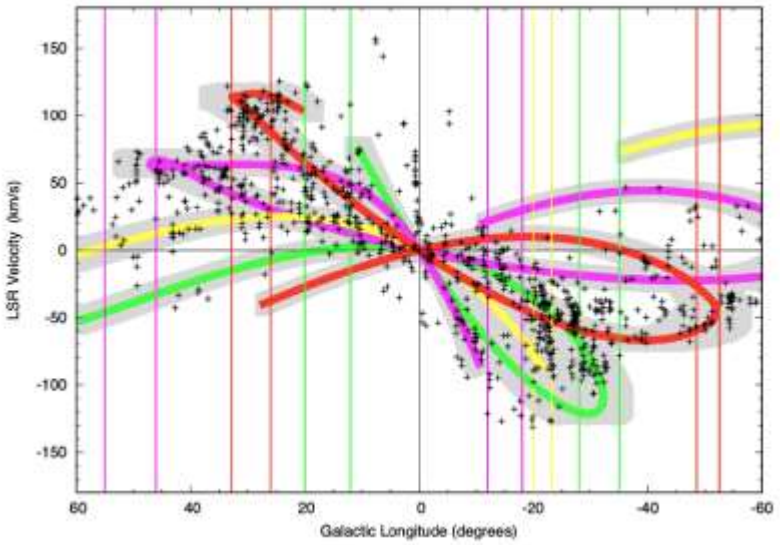
CO map from Dame Hartmann & Thaddeus (2001)

Statistical analysis of the MMB

Green et al. (2017)

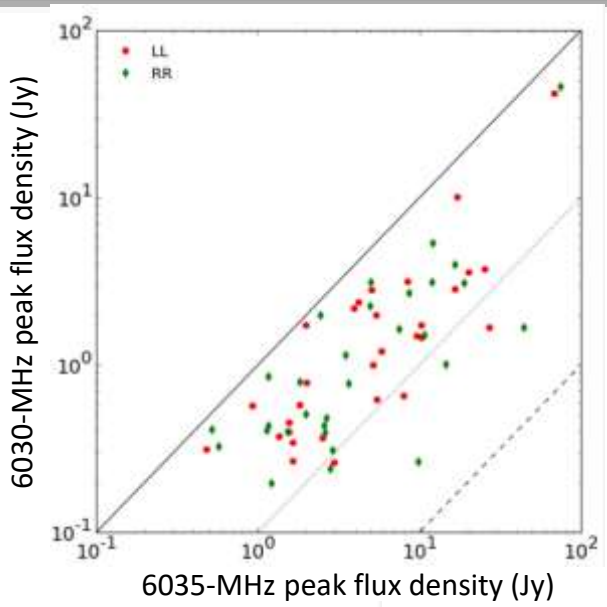
- 972 detections implies a total Galactic 6.7 GHz maser population of ~1290 sources with flux densities > 0.51 Jy
- Strongest is G9.621+0.196 at 5200 Jy, 51 > 100 Jy, 330 > 10 Jy and 118 < 1 Jy
- 7% of the MMB sample show variability of a factor of two
- Weaker masers exhibit greater variability
- Velocity ranges between 28.5 kms^{-1} for G305.475−0.096 and 0.3 kms^{-1} for G37.767−0.214 (median is 6.0 kms^{-1})
- Lower luminosity sources have smaller velocity ranges compared to higher-luminosity sources
- Evidence that brighter sources seen towards arm origins

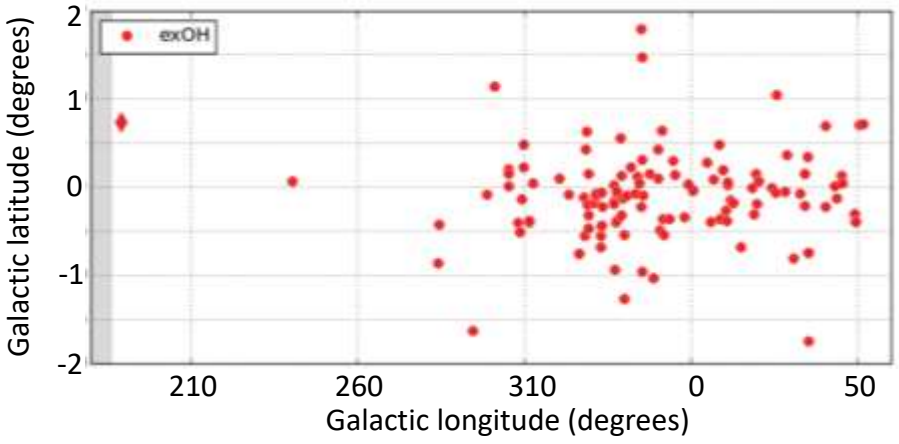


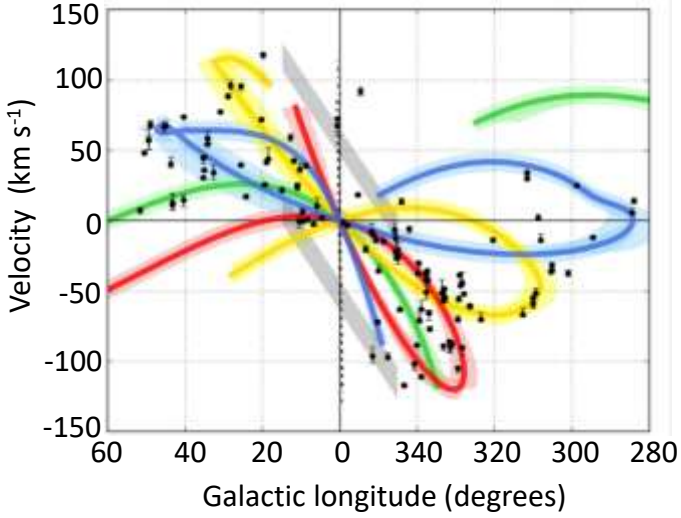


Excited OH from the MMB: Avison et al. (2016)

- 127 (47 new) 6035-MHz OH masers detected in the MMB survey region
- 32 had 6030-MHz counterparts
- About half associated with methanol maser emission
- In the period since Caswell & Vaile (1995) and Caswell (2003) ~20% of sources varied by more than a factor of 2





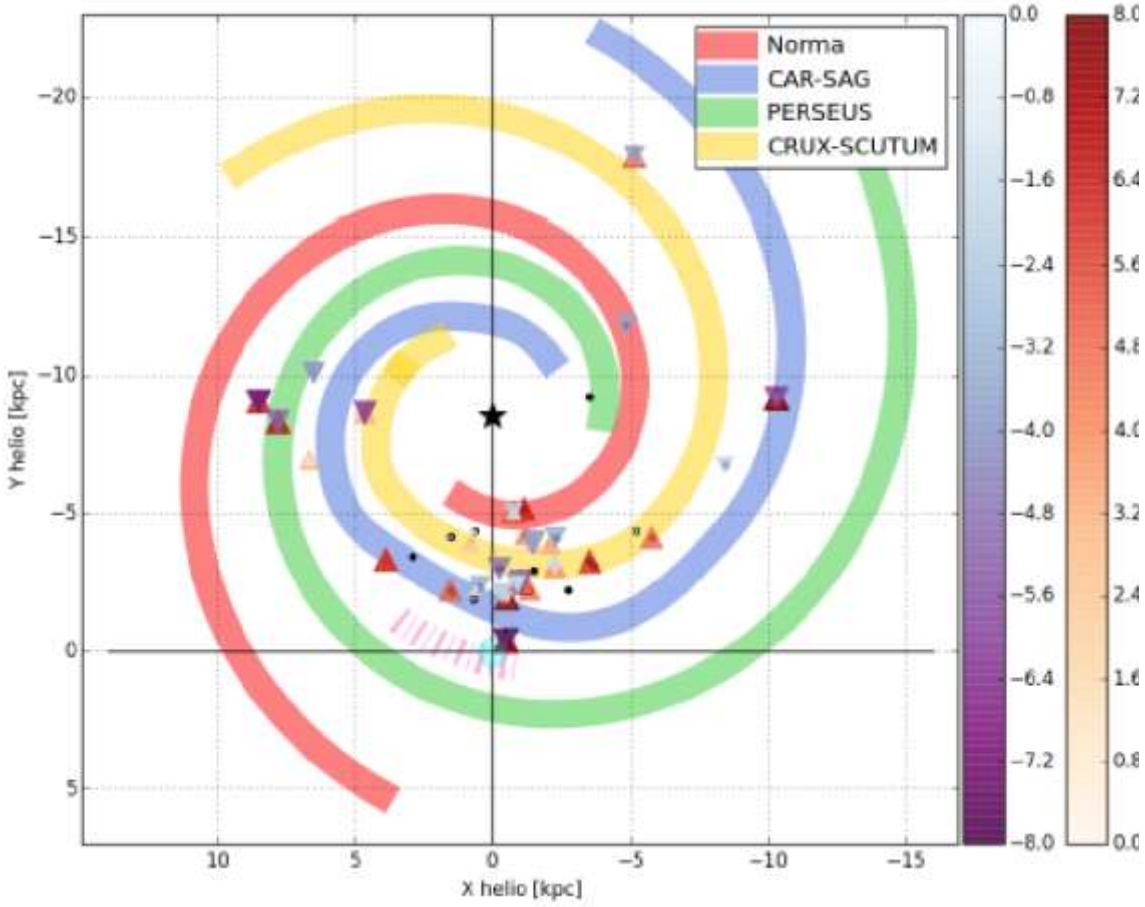


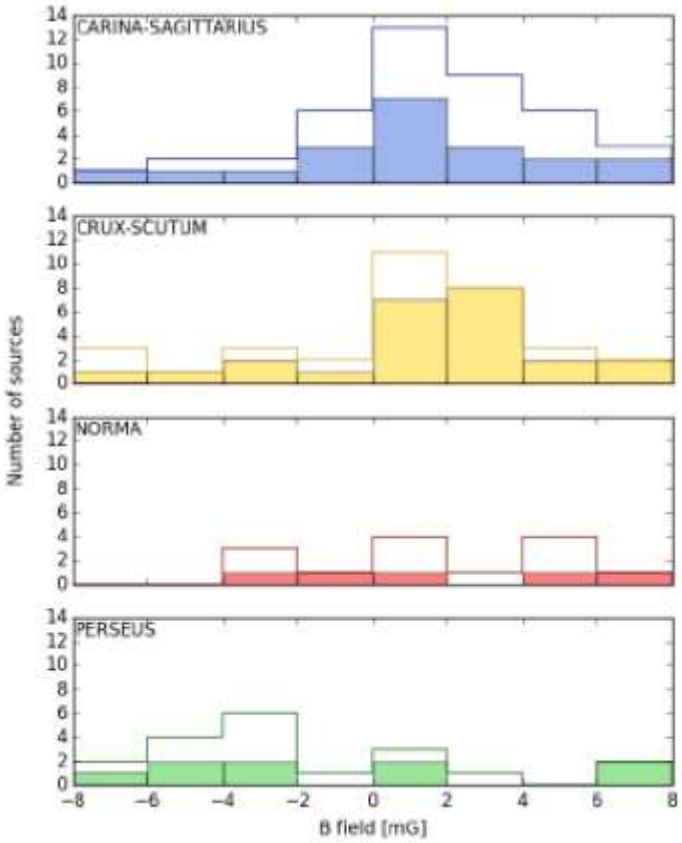
Norma
Carina-Sagittarius
Perseus
Crux-Scutum

Excited OH from the MMB: B fields

Avison et al. (in prep)

- B fields derived for 74 sources with an average magnitude of 3.4mG



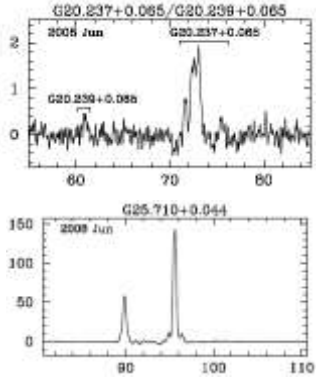


12.2 GHz

Breen et al. (2012a,b,2014,2016)

- 12.2 GHz targeted observations towards (almost) all of the MMB sources using Parkes
  - 431 masers detected (45.3%), ranging from 0.3 Jy up to 976 Jy
  - Only 11 sources > 100 Jy
  - Proposed that 12.2 GHz methanol masers present in the 2nd half of the 6.7 GHz maser lifetime AND HERSCHEL temps agree!

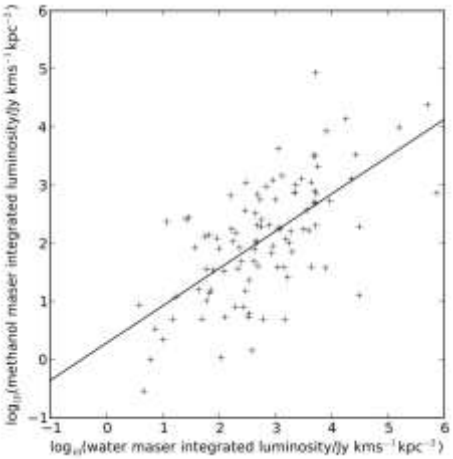


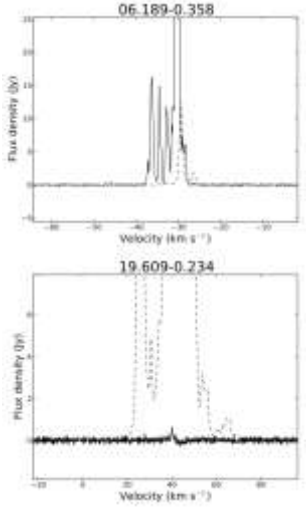


Water

Titmarsh et al. (2014,2016)

- ATCA targeted observations (rms mostly <0.1 Jy)
- 341 (through the GC) to 20 degrees longitude published
- 156 22 GHz water masers detected towards 323 6.7 GHz methanol masers (detection rate 47%) -> higher towards sources with 12.2 GHz



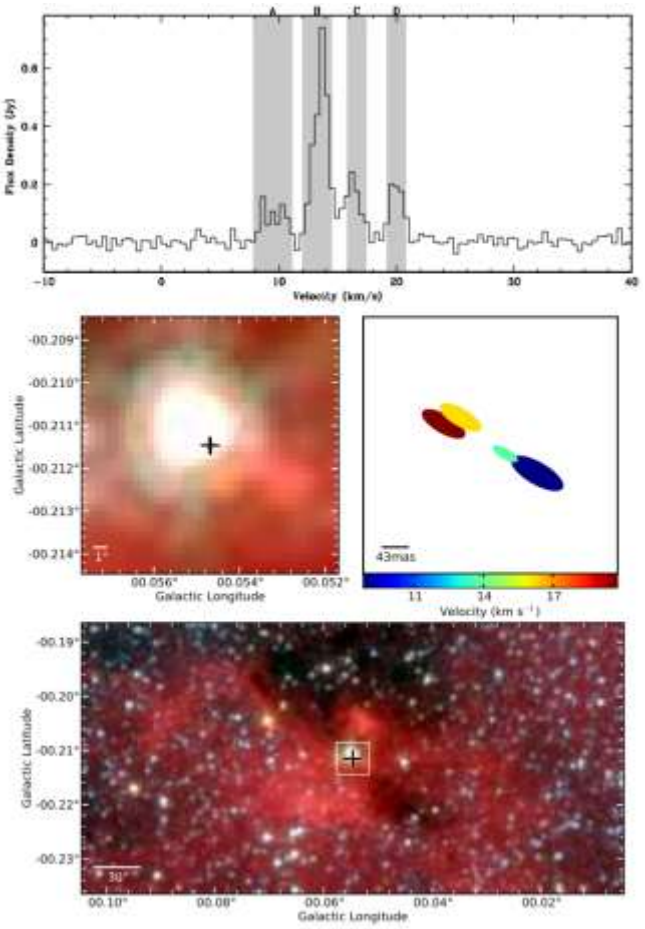


H_2O southern galactic Plane Survey (HOPS)

Walsh et al. (2011, 2014)



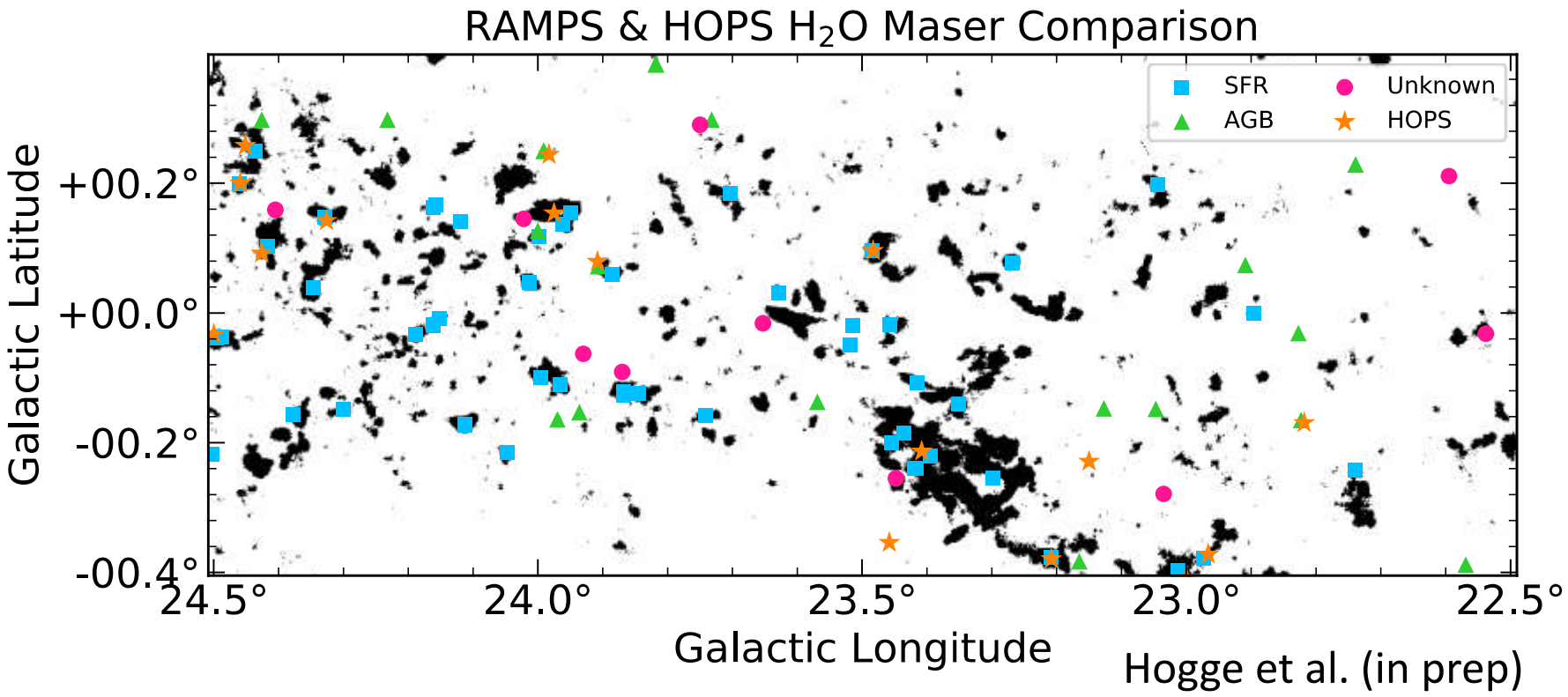
- Initial survey conducted with Mopra and identified 540 maser sites
  - RMS variable and the detection limit mostly ~2 Jy but up to 10 Jy
  - 290° < longitude <30° and latitudes +/-0.5 degrees
- Follow up observations with ATCA for positions identified 631 maser sites
  - 433 of these sites (69%) associated with star formation
  - Water maser sites have fewer spots than those associated with evolved stars but are distributed further
  - Highly variable masers tended to be weaker
  - Small number of linear spot distributions, arranged both parallel and perpendicular to outflows



Data products available at:
https://research.science.mq.edu.au/hops/public/index.php

Radio Ammonia Mid-Plane Survey (RAMPS)

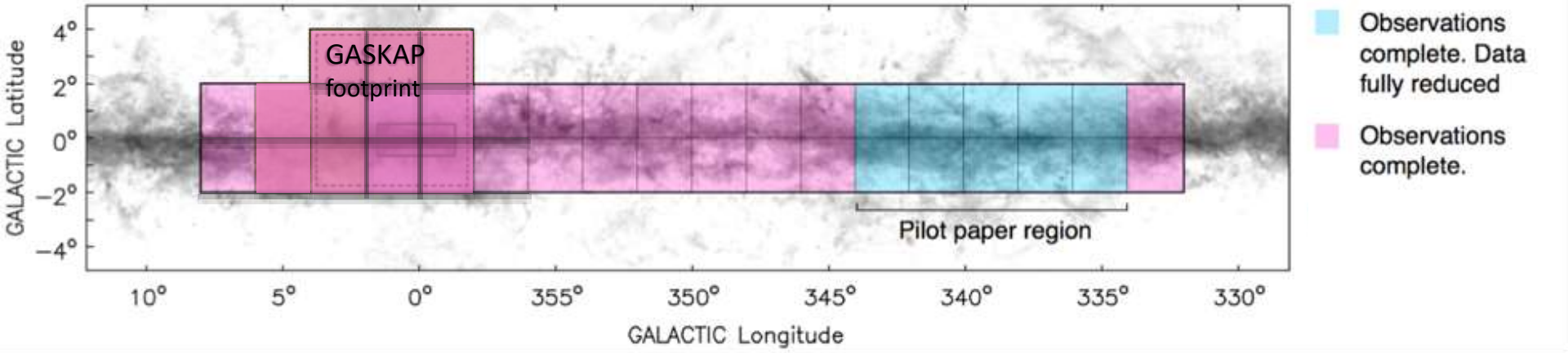
- K-band Focal Plane Array on the GBT (Jackson, Hogge et al.)
- 325 water masers detected within 6.5 square degree pilot region
- Observing bandwidth ~300 km s^{-1}, centered on 0 km s^{-1}.
- rms of 0.4 K in 0.12 km s^{-1} channel



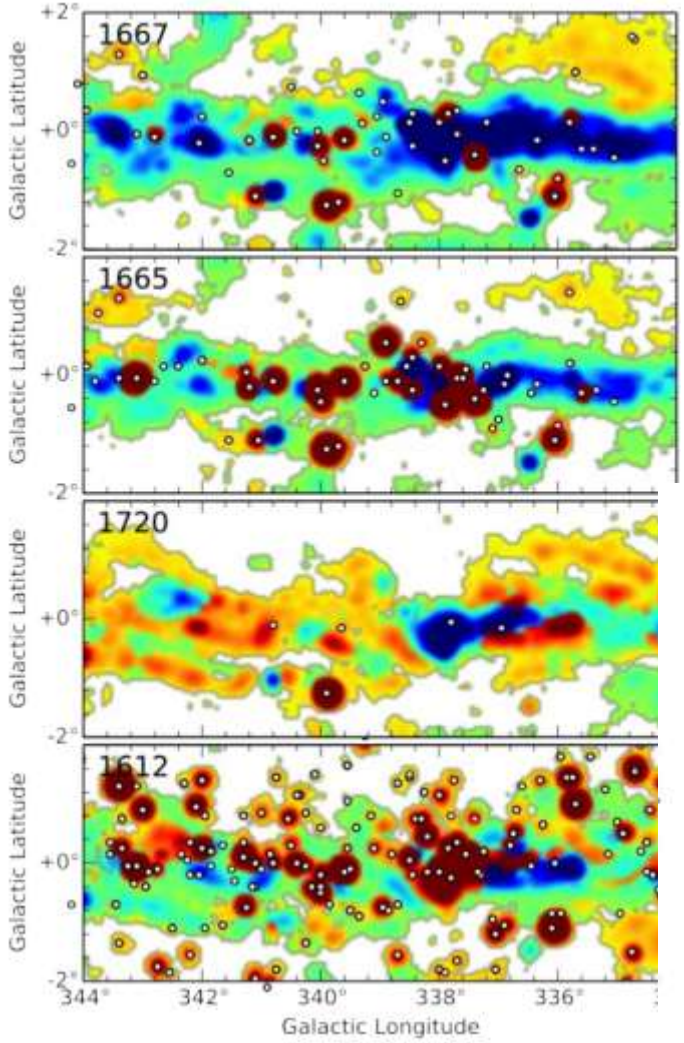
SPLASH Dawson et al. (2014)

- Southern Parkes Large-Area Survey in Hydroxyl
- Unbiased, fully-sampled, large-scale diffuse OH survey of the Milky Way + 1.6-1.7 GHz continuum
- All four ground state transitions of OH 1612, 1665, 1667, 1720 MHz
- Low resolution, high sensitivity:
- Effective HPBW = 15’
- RMS 65 mJy in 0.18 km s^{-1} channel
- 156 square degree coverage



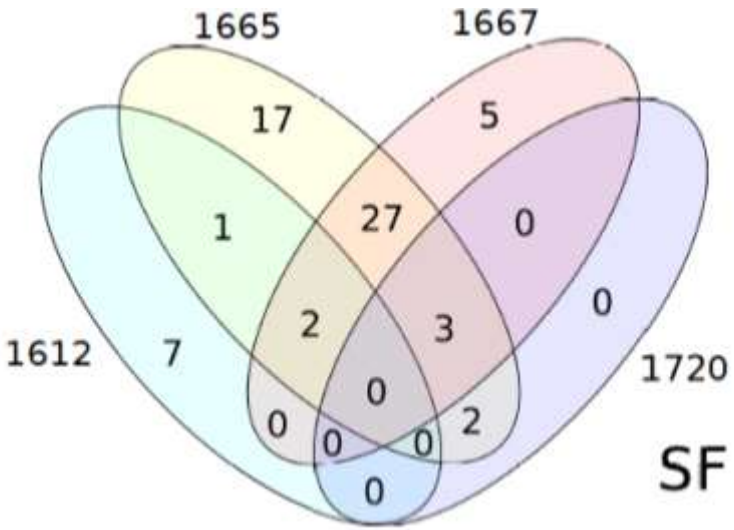


SPLASH results in the pilot zone



Dawson et al. (2014)

- Parkes detections all followed up with the ATCA (Qiao et al. (2016)
- 215 OH maser sites were detected – 111 were new
- 64 (30%) associated with star formation

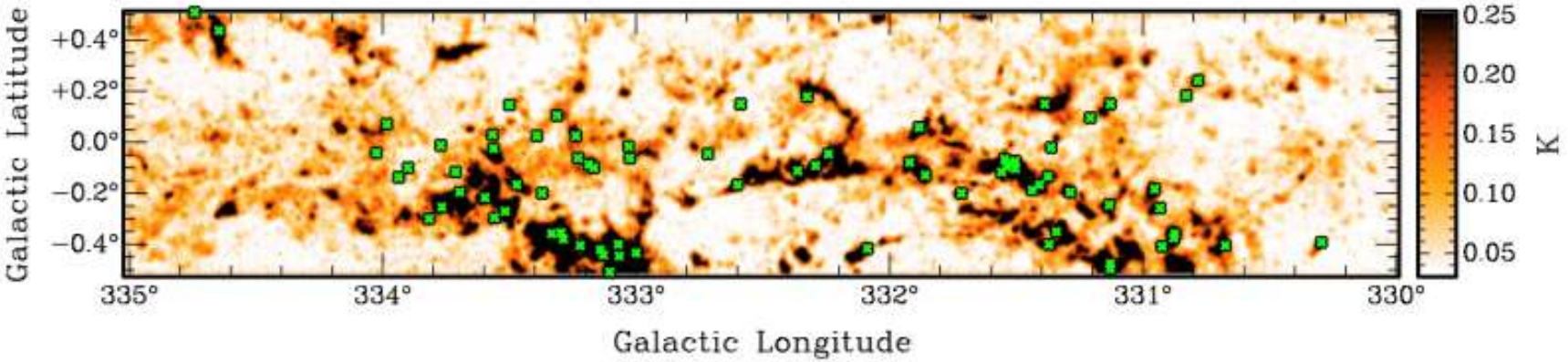


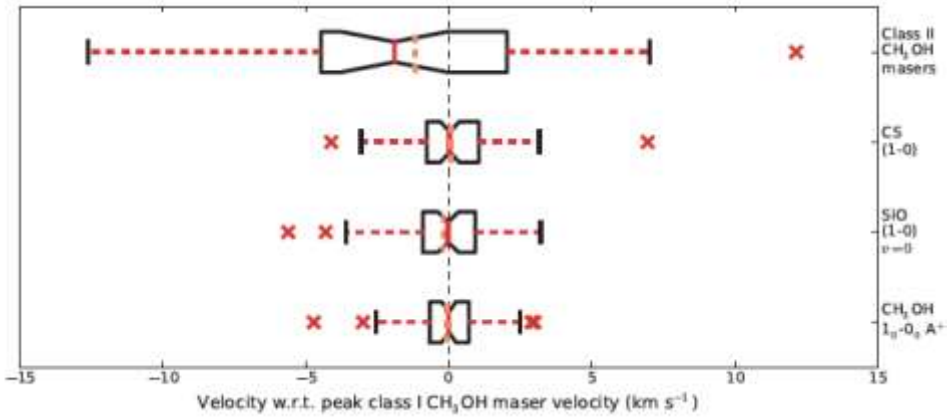
Qiao et al. (2016)

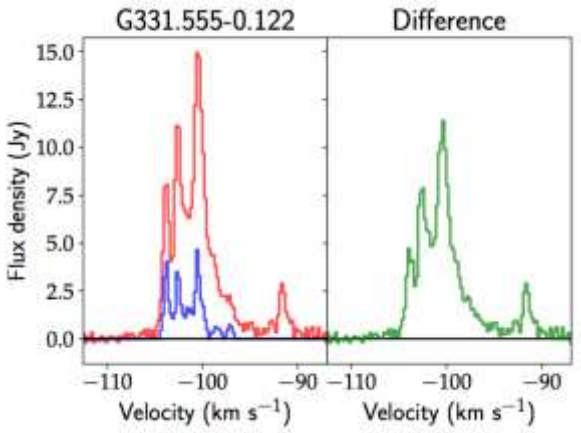
See P22 for more details

MALT45 Jordon et al. (2015, 2017)

- 77 44 GHz class I methanol masers detected across 5 square degrees, 42 not associated with other masers







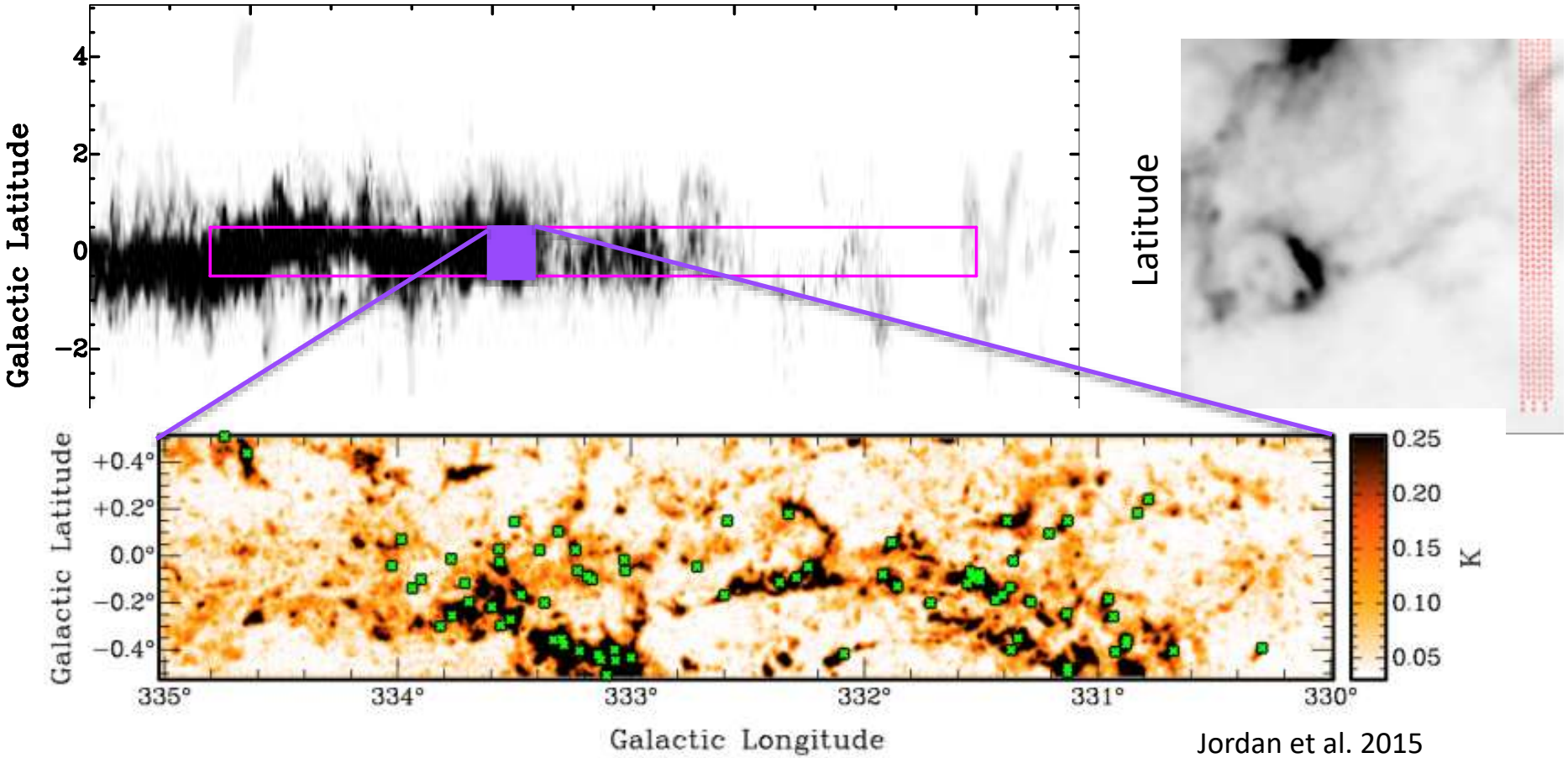
Dense Gas Across the Milky Way - The 'Full-Strength' MALT45

- ATCA legacy survey (2700h)
- 90 square degrees of the Southern galactic plane at 7mm (dense gas, shock tracers, recombination lines, class I methanol masers, SiO masers….)

  – On the fly mapping, 6 seconds integrations, scanning only in latitude – fully sampled at the highest frequency
  – Sensitivity to see typical 400 Msol out to 15 kpc (corresponds to ~44 mK in a single spectral channel)
  – Velocity resolution of ~0.2 km/s, and coverage of ~700 km/s +
  – Started observing end of May 2017 and have so far observed ~200 of the 300 allocated hours this semester



Dense gas across the Milky Way – The ‘full-strength’ MALT45



Jordan et al. 2015

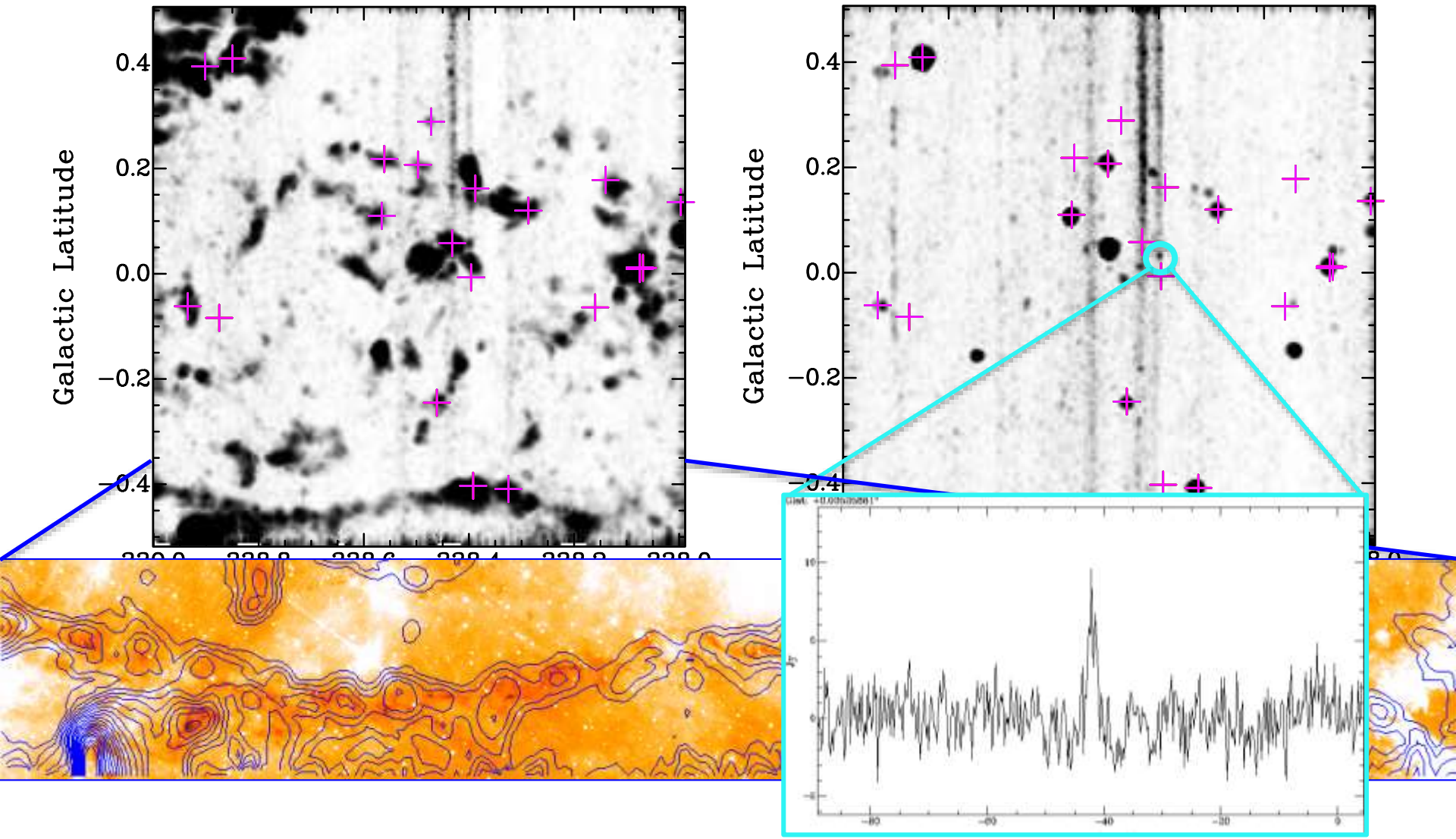
CH_3OH 1_0–0_0 A+	48.37246	Thermal	58	H53α (RRL)	42.95197	Thermal	65
$C^{34}S$ (1–0)	48.20694	Thermal	58	SiO (1–0) $v = 2$	42.82048	Maser	66
H51α (RRL)	48.15360	Thermal	58	SiO (1–0) $v = 3$	42.51934	Maser	66

The team

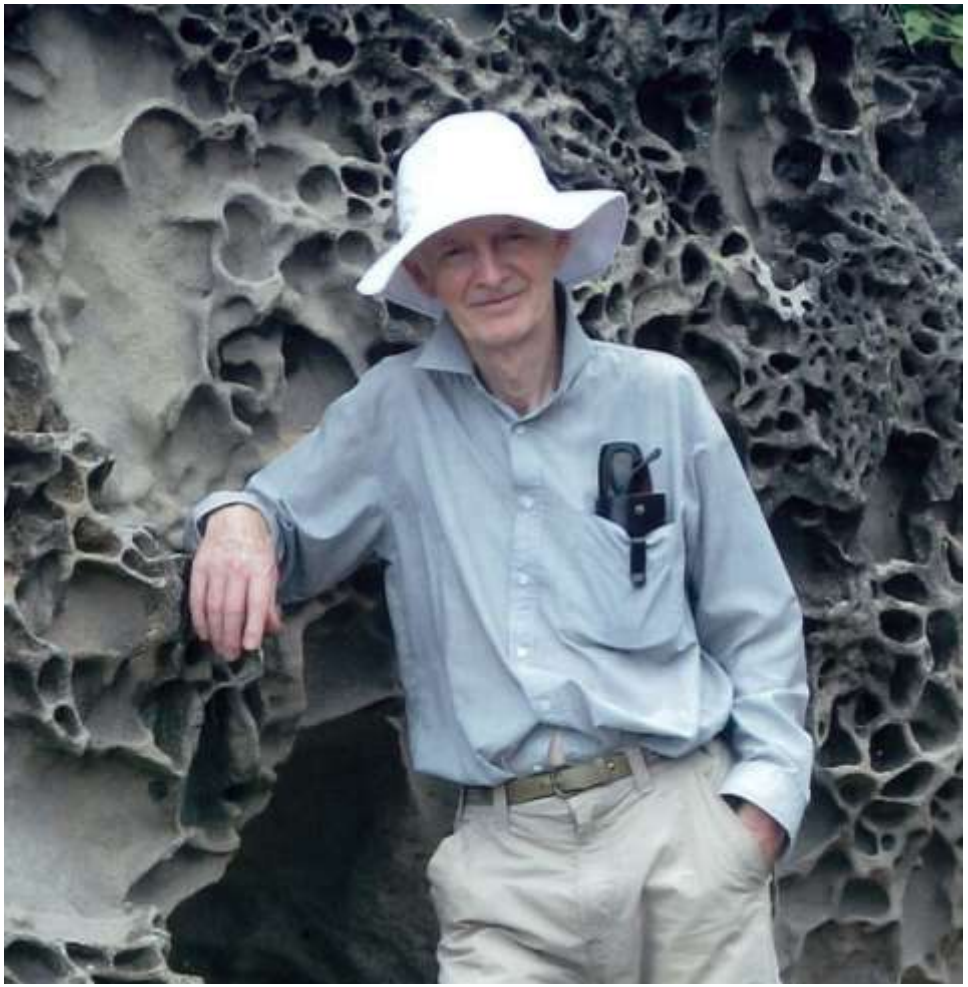
Shari Breen (USyd)
Andrew Walsh (Curtin)
Simon Ellingsen (UTas)
Chris Jordan (Curtin)
Gavin Rowell (UAdelaide)
Paul Jones (UNSW)
Maria Cunningham (UNSW)
Michael Burton (Armagh)
Christoph Federrath (ANU)
Yanett Contreras (ULeiden)
Jo Dawson (UMacquarie)
Nicola Schneider (Saclay)
Maxim Voronkov (CASS)
Juergen Ott (NRAO)
Phoebe De Wilt (UAdelaide)
Jimi Green (CASS)

Viktor Tóth (Hungry)
James Jackson (UNewcastle)
Peter Barnes (Florida)
Steven Longmore (Liverpool)
Balt Indermuehle (CASS)
Gary Fuller (Manchester)
Adam Avison (Manchester)
Rowan Smith (Manchester)
Leo Bronfman (Chile)
Giles Novak (Northwestern)
Laura Fissel (NRAO)
Jouni Kainulainen (MPIA)
Chris Phillips (CASS)
Lucas Hyland (UTas)
Tiege McCarthy (UTas)
Nigel Maxted (UNSW)

Dense gas across the Milky Way – The ‘full-strength’ MALT45



Jim Caswell





Summary

- Increasing number of large maser surveys at various stages of completion
  - MMB done although lots of follow up papers still to come (MERLIN spot maps, continuum, ammonia, more water, class I….)
  - HOPS completed
  - SPLASH full region and polarisation data still to come
  - New MALT45 survey has a long way to go!
- Combined these provide a huge resource for future studies



